# LIFE CYCLE INVENTORY FOR AUSTRALIAN BUILDING MATERIALS

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## Abstract

This paper discusses challenges to developers of a national Life Cycle Inventory (LCI) database on which to base assessment of building environmental impacts and a key to development of a fully integrated eco-design tool created for automated eco-efficiency assessment of commercial building design direct from 3D CAD. The scope of this database includes Australian and overseas processing burdens involved in acquiring, processing, transporting, fabricating, finishing and using metals, masonry, timber, glazing, ceramics, plastics, fittings, composites and coatings. Burdens are classified, calculated and reported for all flows of raw materials, fuels, energy and emissions to and from the air, soil and water associated with typical products and services in building construction, fitout and operation. The aggregated life cycle inventory data provides the capacity to generate environmental impact assessment reports based on accepted performance indicators. Practitioners can identify hot spots showing high environmental burdens of a proposed design and drill down to report on specific building components. They can compare assessments with case studies and operational estimates to assist in eco-efficient design of a building, fitout and operation.

**Keywords:** Environmental assessment, commercial buildings, industry foundation classes, 3D CAD, life cycle inventory

## 1. BACKGROUND

The need to incorporate Ecologically Sustainable Development (ESD) principles into human settlements has been articulated since the release of the Brundtland Commission Report: “Our Common Future” [1]. The Rio Declaration [2] and the Agenda 21 Report from the United Nations Conference on Environment and Development [3] subsequently called for support from all Nations. In response, the Council of Australian Governments’ National Strategy for Ecologically Sustainable Development (NSESD) was published in 1992 [4]. The NSESD defined ESD as development that “uses, conserves and enhances the community’s resources so that ecological processes on which life depends are maintained and the total quality of life, now and in the future, can be maintained”. In 1997 a national “CGI-97 Directions Forum” was called to develop strategic planning required for the NSESD to address built environment challenges [5,6,7]. This Forum recognised that the total of all buildings’ share of escalating global environmental deterioration is very significant. In the United States of America, for example, it ranges from 15% to 45% of total burdens for 7 environmental stress categories shown in Figure 1 of such burdens [8].

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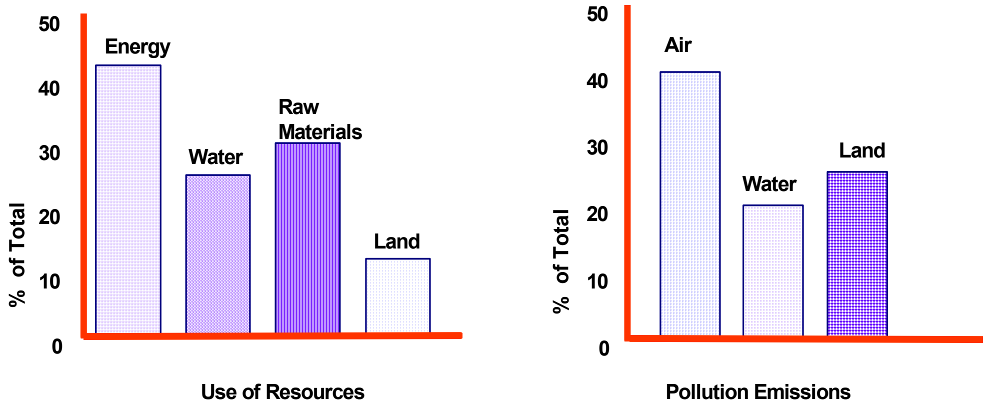



**Figure 1 Building environmental burdens (USA data)**

This forum also agreed that the built environment encompassed buildings from a "whole of life" perspective including planning, design, construction, procurement, maintenance, use and disposal as well as interactions with services, infrastructure, occupants and the natural environment [5,7]. Many studies [9 to 13] confirm that sustainable building is becoming more widely understood and accepted that:

- The industry must move toward more sustainable practice at an enhanced rate,
- Governments have a lead role to ensure sustainable practices are increased,
- There is a need for regulation of minimum sustainable building requirements,
- Commercial opportunity will arise firstly in energy, water and waste and as it becomes more economically viable uptake will increase.

In 2001, the Cooperative Research Centre for Construction Innovation (CRC CI) was established, to meet property, design, construction and facility management needs, with a Commonwealth grant and support from industry, research and other governments [14]. CRC CI program B: "Sustainable Built Assets" combines life cycle assessment, whole of life costing and whole of life performance assessment to deliver a suite of CAD-integrated cost and environmental assessment tools for commercial buildings [14,15]. These are tools that can enhance the decision-making process to deliver superior built environment outcomes in building design, fitout and operation [15].

## 2. Introduction

At present designers adopting ESD criteria do not have either a nationally accredited method to evaluate ESD in building performance or an integrated information technology (IT) to capture such considerations in the design process. This situation is depicted in Table 1, a matrix of design project variables aligned with IT levels progressing to integrated IT solutions based upon ESD-LCA-CAD linked databases. The design solution that the CRC CI has developed is called LCADesign, a tool using interoperable building design software to deliver environmental assessments. This tool takes off in real time automatically from 3D CAD and provides reports of environmental measures on which to base accepted international and new domestic environmental impact assessments. From proposed designs practitioners can identify eco-hot spots and drill down on design components as well as compare as designed environmental impacts with operational estimates and performance benchmarks [15].

Nevertheless, the delivery of interoperable databases such that CAD can generate such aggregated and component specific reports presented significant challenges.

**Table 1 Matrix of project IT change toward ESD**

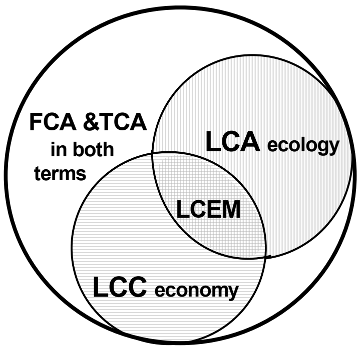
| Levels | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Organisation** | Paper based | Electronic paper | Project co-ordination | Project integration | Intelligent project |
| **Design Process** | Separate black box | Separate black box | Process co-ordinated | Virtual design team | Integrated project team |
| **Modelling** | Sequential, independent | Bi-party co-operation | Coordinated design | Concurrent design | Concurrent design |
| **Information Sharing** | Paper drawings | Sequential independent | 3D CAD | Simple object model | Interactive design |
| **Technical Facilities** | 1-way design share | 2D CAD | 2-way share design | Share design in step files | Information rich, object model |
| **ESD tools** | QS | LCA & QS separate | LCA-QS linked | LCA-CAD-QS linked | ESD-LCA-CAD-QS integrated |

The objective of this paper is to present challenges faced and strategies adopted for delivery to LCADesign of an environmental database that is to deliver:

- National industry datasets for building design and construction applications,
- An extensible domestic inventory functional within an accepted global model,
- Integrated data exchange across a range of external formatting demands,
- Rigorous transparent data compilation for ongoing assessments as well as
- Even distribution data quality to ensure acceptance by all stakeholders.

## 3. Whole of life performance assessment

It was perceived that to meet such challenges the solutions needed lay in the domain of full and whole of life costing methods that provide economic as well as environmental assessment of options as depicted in Figure 2 [16].




- Life Cycle Assessment (LCA) to account for environmental emissions/ resources.
- Life Cycle Costing (LCC) to assess investment as discounted cash flow over time.
- Total Cost Assessment (TCA) to bring environmental costs out of overheads.
- Full Cost Accounting (FCA) of externalities.
- Life Cycle Environmental Management (LCEM) to exploit any of these.

**Figure 2 Domains of full cost assessment methods**

For decision-making considering whole of life assessment LCA is useful because it takes a systems approach [17,18]. It is because any group of industrial operations can be regarded as a system that an inventory of all resource inputs and emission outputs crossing the system boundary can be counted and analysed. To illustrate such a system, an example of the built environment as such a system is depicted in Figure 3.

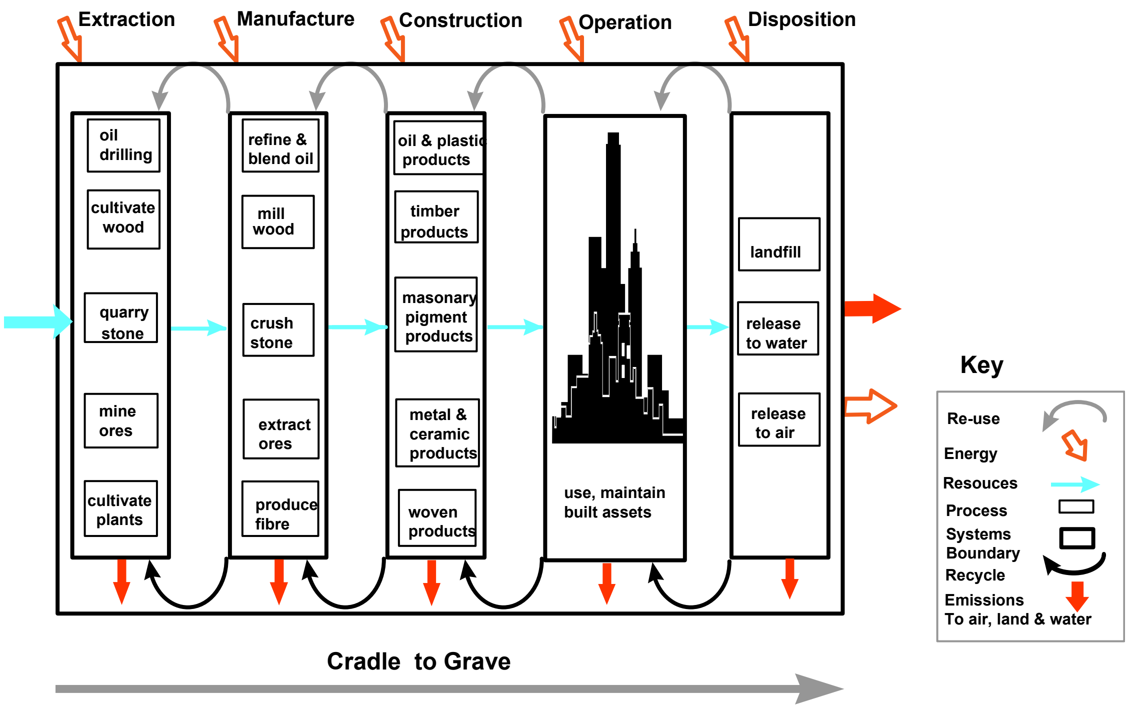



**Figure 3 Diagram of the built environment as a system**

## 4. Scope

While currently conducted in a "cradle to construction" system boundary the scope of LCADesign assessments will become "cradle to grave". This means that over a given building design life, the scope of work includes all known environmental flows of resources from and emissions to air, land and water in acquisition, component manufacture, construction, operation and disposition. While capital equipment, employee facilities and activities are excluded LCADesign assessments do include:

- Mining, crushing and chemical use in extraction and processing of raw materials,
- Acquisition of cultivated, collected or harvested agricultural product,
- Fuel production to supply power and process energy and transport of materials,
- Process energy and transport for raw, intermediate and ancillary materials,
- Resources consumed in processing such as lubricants, tyres, energy and
- Packaging, maintenance, renewal, recycling and disposition operations.

## 5. Method

As a cost accounting method LCA has been used to determine the costs to the environment of products, services, projects and facilities particularly costs of waste management, energy reduction, natural resource depletion as well as human and ecosystem health [16 to 20]. In environmental management it is used in process analysis as well as procurement and product evaluation to:

- Benchmark improvement trends in design, construction, manufacture and use,
- Underpin decision making and performance of policy, goals and investment and
- Target areas of greatest impact to reduce burdens by changed practice [16 to 19]

Normative references for LCA methods are sourced from the International Standards Organisation: Environmental Management Systems [21]. Adoption of the ISO/TS 14048 data documentation format [22] is also being considered to facilitate CRC CI

LCI interoperability. LCA involves:

- Life Cycle Inventory (LCI) to assess resource depletion and emissions to air, land and water,
- Life Cycle Impact Assessment (LCIA) to determine environmental impacts of such burdens listed in LCI and
- Life Cycle Improvement Assessment compares LCA and LCIA against improvement criteria.

This paper relates to LCI rather than LCIA and because of the lack of accepted Australian methodology, LCADesign exploits accepted overseas LCIA for such as eutrophication, greenhouse global warming potential, human and ecological toxicity.

## 6. The challenges

### 6.1. Delivering a national product inventory

The first challenge was to capture representative data and generate national datasets for Australian products used in building and construction industry applications. To meet this challenge the CRC CI LCI database was based upon an existing Model developed by Boustead Company Limited (BCL) because it provided a physically rigorous inventory of industry operations. This BCL model has since served as a foundation for developing a new inventory of Australian domestic operations. In developing such inventories the amount and type of material comprising each product is typically derived from industry reports and specifications of component quality, quantity, and operations involved. CRC CI documentation considers market share, locations, technology, and transport involved as well as the Parent/Company, period of commitment to improved environmental performance concerning:

- Process technology “state-of-art “ for each operation,
- Reductions in process raw material, energy and water consumption,
- Reductions in process emissions, effluents and solid waste, as well as
- Increased efficiency in transportation and distribution systems.

### 6.2. Delivering an inventory for imported product

The CRC CI LCI database also needed to cover imported products used in building applications. Because the BCL model contains an extensive inventory of international fuel, energy and industry operations its coverage is considered global. It contains core national energy and transport operations for most countries and is also supported by well-documented international studies by Ian Boustead and colleagues [19, 21, 22, 23]. The core of both domestic and imported operations is highly redundant and while this provides compactness it means that strict protocols are required to protect database integrity. With such protocols for compiling the core of domestic operations the model can continue to draw on its global core to provide inventory reports for both domestic and imported product.

### 6.3. Extensive building sector operations coverage

The building and construction sector uses an extensive range of building materials and operation used in construction and fitout. The BCL Model and CRC CI LCI database covers fuel, energy, water and raw materials acquisition, primary and secondary processing and transport operations. Bulk handling operations, for example, cover gasses, sands, clays, minerals, ores, masonry, agricultural, forestry, limestone, aggregates and concrete. Fabricated products are serviced from a selection of chemicals, metals, cements, glasses, ceramics, timber, papers, boards and plastics. Transport options include wholesale, retail and consumer delivery, rigid, articulated and tipper trucking as well as rail freight and circuit working. Gas and oil pipeline selections are available along with civil, military and consumer aviation as well as various shipping operations. Emissions are designated as going to air or water from fuel production and fuel use, transport or processing while solid waste is classed by type, source and as arising from fuel production, fuel use and transport operation.

### 6.4. Adaptability for the future

Over the longer term, LCADesign will require capacity for many new products and refining in line with relevant industry standards. While the model can be updated as required and is extendable protocols were essential to facilitate maintenance and updates while avoiding database corruption. To address the ongoing need for upgrading the CRC CI LCI has been developed for use, for example, like a juke-box to load and unload datasets stored outside the working model. This approach also facilitates future work with new core data as well as for future Australian or indeed other countries' data needs. This ensures that different quality inventory datasets can be adopted to cover different quality standards and facilitates future development tailored to specific industry sectors, states, regions or nations needs.

### 6.5. Demanding integrated data exchange

As previously stated advancement of IT may provide many solutions but it also presents ongoing challenges. One CRCI LCI challenge was to permit integrated data exchange compliant with a range of formatting requirements. This challenge was also met by adopting protocols to provide a secure working range for building product LCI codes that are essential to generate data for export to LCADesign. Default reasoning rules built on an accepted building element nomenclature (for example the Australian Cost Management Manual nomenclature) associated with Industry Foundation Class (IFC) information embedded in the 3D CAD model are used to map the association between building elements and the building product LCI. A feedback loop is also required to allow for additional building products or building elements to be defined and analysed.

### 6.6. Transparency to stakeholders

For practitioner confidence, it is essential that that information is clearly presented so users understand how the CRC LCI is developed. With each building component the production sequence is depicted in flowcharts and uniquely coded tables are constructed for each step, as a unit operation, based on physical inputs and outputs that are mass balanced to unity. Equally, all energy inputs therein must obey physical laws of conservation of energy. The Model is employed to calculate LCI results and export data to generate LCADesign reports. Calculated burdens are also classified and LCI reports generated such that the methods, results, discussion and conclusions are documented for each product. Such reports cover gross energy, fuel, feedstock and raw material resource consumption considering total embodied, highest intensity operation, transport and reliance on renewable sources. Emissions to air, water and land are considered separately as total embodied, highest intensity operations and hazardous/regulated share as waste, effluent and air pollutants. There is a provision in the ISO environmental management standards that inventories undergo sensitivity and verification procedures and external audit to which CRC CI LCI work adheres.

### 6.7. Broad stakeholders acceptance

The work has to be presented clearly to a broad cross section of stakeholders and in presenting information some concepts and graphical formats are found to be more acceptable that others. The ecological footprint is one concept promoted in the Urban Air Pollution Report to define the impact of development on the natural environment [25]. It recommends: *"At a micro-level the concept of building fingerprint has been advanced by Baldwin and Yates as a means of evaluating all significant aspects of industrial or commercial activity for environmental impacts. The objective is to minimise energy (and resource) consumption and emissions (to air land and water) generated with the construction, operation, maintenance and utilisation of individual buildings"* [9]. Results from LCA work may also be depicted in an "*eco-star"* diagram as shown in Figure 4, a graphic of normal burdens from a typical house as a solid outer line compared to best practice as a bricked area and ESD practice as a dark area [7].

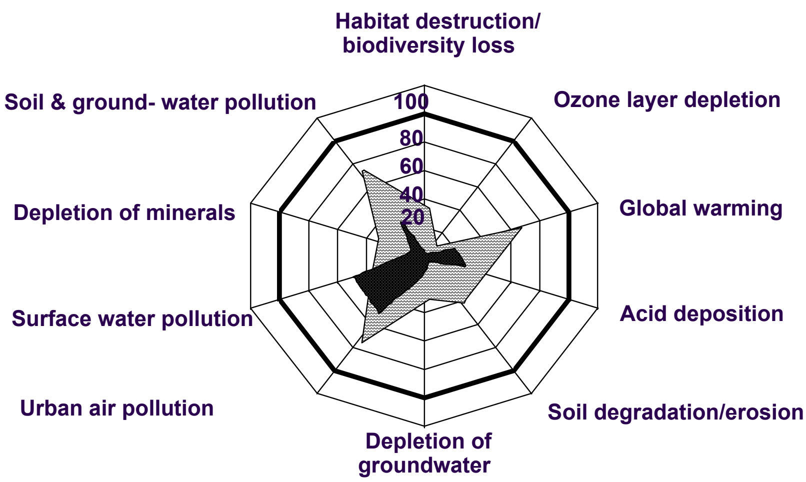



**Figure 4 Ecological footprint of a typical house (USA data)**

## 7. Conclusions

This paper outlined challenges to developers of a CRC CI environmental inventory on which to base assessment of building environmental impacts. It provides information to a fully integrated eco-design tool created for automated eco-efficiency assessment of commercial building design direct from 3D CAD. Challenges included compilation of national datasets for imported and domestic products. This involved comparably even data quality distribution representative of an extensive building and construction sector. Based initially upon an existing Model, an extensive national inventory database has been developed that is extensive in coverage of bulk and fabricated building products and supported by well-respected and verified studies. Protocols were described for integrated data exchange compliant with a range of formatting requirements for upgrading to specific quality standards, industry sectors or regions for LCADesign to permit comparison of designs built here as well as other countries.

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